# Acoustic Detection of Submerged Objects

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## LONG TERM GOALS

The long term goal of the project is to enhance our ability to detect submerged objects using acoustics. We aim to use our knowledge of the irregular spatial and time structure of sound in the ocean in order to improve the design of sonar apparatus and the way in which it is employed in operational situations. The work will apply to passive sonar when the submerged object is a sound source. It will also apply to active sonar when the submerged object is silent.

## OBJECTIVES

It has been established both theoretically and experimentally (Fig. 1) that sound, when propagating in the ocean, has a tendency to form long irregular features where the sound concentrates resulting in relatively high intensities. In between there can be regions where the sound level is extremely low, "silent" areas. We now know a good deal about why the ribbons form, what determines their position and lifetime and how they change when the sound source moves. The main scientific aim of this project is to investigate how the high intensity features change as the acoustic frequency varies. This will allow us to adapt the modes of deployment and operation of both passive and active sonar so as to optimise target acquisition. A second aim is to investigate how the existence of the irregular features affects the performance of sonar arrays. This should prove helpful in designing such arrays and determining the limitations that a real ocean can place on their performance.

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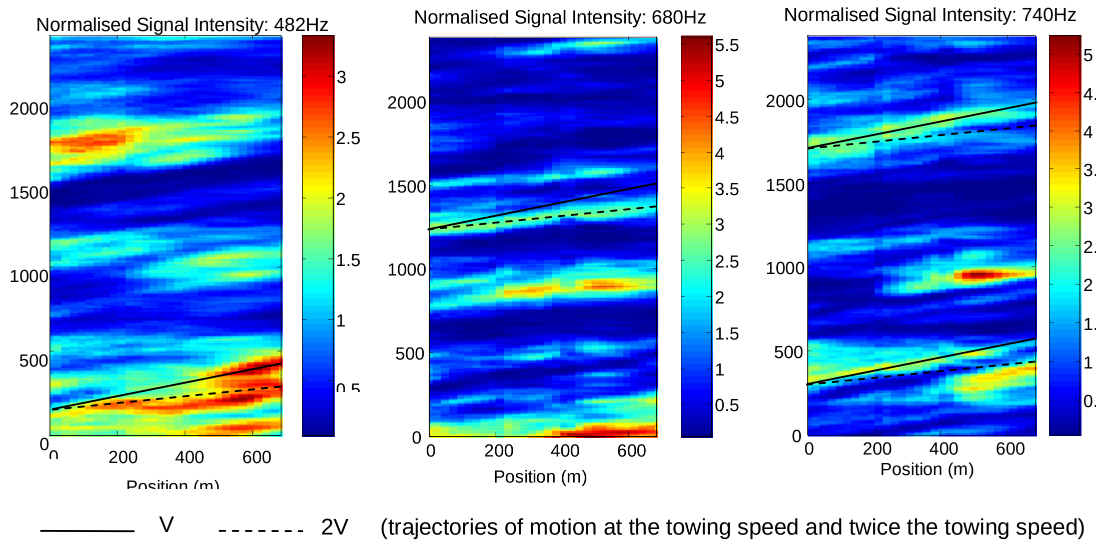



Figure 1 High Intensity Features Viewed from Above

[*Intensities at three different acoustic frequencies recorded by a horizontal array towed transverse to the direction of sound propagation. They show high intensity regions with transverse dimensions of a few hundred meters*]

## APPROACH

Our knowledge of the origins and behaviour of high intensity acoustic ribbons in the ocean has made much progress in recent times. The manner in which they are associated with ocean internal wave features is now clear and it is possible to predict the strength of such ribbons, their separation and longitudinal extent on a statistical basis. Recent studies have also shown how the ribbons behave when the sound source moves. Some important questions that still remain unanswered concern the horizontal structure of the ribbons and their behaviour as the acoustic frequency changes. These are the main objects of investigation in this project.

It is proposed to conduct the study using numerical simulations, theory and the analysis of experimental results. Theory of the cross-correlation between intensity fluctuations at different acoustic frequencies can provide average quantities and expectation values while numerical simulations allow us to vary the frequency in a controlled manner and observe the consequences. Both these approaches will be used. Real ocean experiments, on the other hand, not only allow us to confirm theory and numerical simulations against the real thing, but usually provide some unexpected extra insight and information.

Ocean acoustic experiments are, however, very expensive operations and often difficult to carry out. We are particularly fortunate in having access to the results of an ocean acoustic transmission experiment that addresses two important questions that we wish to study. These are the dependence of the high intensity ribbons on acoustic frequency and also their structure in the horizontal transverse to the direction of propagation. The experiment was carried out by the British Ministry of Defence in April l989 in the sea area south of Maderia. The data has been made available to the Cambridge Group under Dr. Uscinski who has worked closely with the British Ministry of Defence for the last 30 years.

The experimental data has been analyzed to provide confirmation of the theory governing the strength of the high intensity features, their structure in the horizontal transverse to the direction of propagation and how they behave and are correlated at the different acoustic frequencies.

Dr, B. Uscinski, the Principal Investigator, is carrying out the theoretical aspects of the project and directing analysis of the experimental data in Cambridge. Dr. D. Rouseff is providing numerical simulation results from his work in APL, Seattle, allowing us to consider how these effects might apply in the shallow water of the China Sea.

**THEORY**

A theoretical description of acoustic intensity fluctuations in the ocean has been developed on the basis of the parabolic equations for the fourth moment of the scattered field. This approach is used to treat the specific problem of the transverse dimensions of the high-intensity ribbons and their behaviour as the source and receiver move. Relevant parts of this theory appear in the paper "Horizontal Structure of Acoustic Intensity Fluctuations" by B.J. Uscinski and J.R.S. Nicholson, which has been submitted for publication in the Journal of the Acoustic Society of America. The moment equation method has also been used to derive the cross-correlation of intensity fluctuations at different acoustic frequencies, and the results have been applied to the experimental data mentioned above. The theory is the subject of a paper by B. J. Uscinski "Cross-correlation of Intensity Fluctuations at Different Frequencies" which has been submitted to the journal Waves in Random and Complex Media.

**EXPERIMENT**

The acoustic transmission referred to above was carried out by the British Ministry of Defence in April 1989 in the sea area south of Maderia over the Maderia abyssal plane. Two vessels made parallel courses at a separation of 65 km. One carried an omnidirectional sound source and the other towed a linear array of hydrophones as shown in Fig. 2.

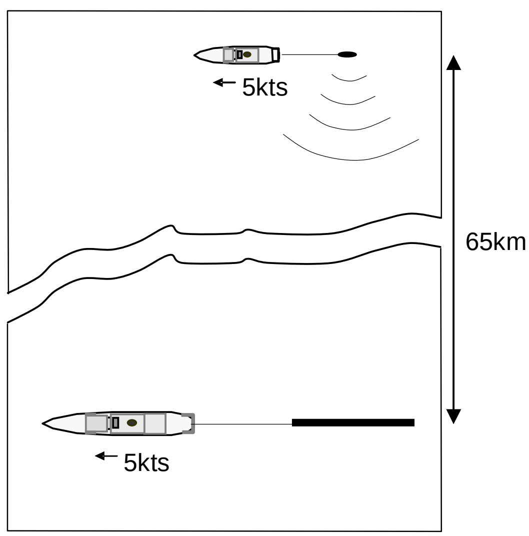



Figure 2   Disposition of the experimental vessels.

[*Shows two vessels steaming at 5 kts parallel to each other 65 km apart, one with a point sound source and the other towing a receiving array*]

The received acoustic intensity is shown in Fig. 1 as a function of time and of position along the array. Most striking are the bands of high intensity encountered by the hydrophones as they are towed horizontally across the "ribbons" predicted by theory. This is the first time that we have experimental data allowing us to study the horizontal width of such ribbons. We also note the regions of very low sound strength in between the ribbons. During the trial the sound-speed profile was measured by numerous XBT casts. Some of the results are shown in Fig. 3. This oceanographic data was used in connection with standard ocean internal wave models and acoustic propagation

theory in order to complement our understanding of the ribbon structure of sound in the ocean and allow it to be utilized for detection purposes.

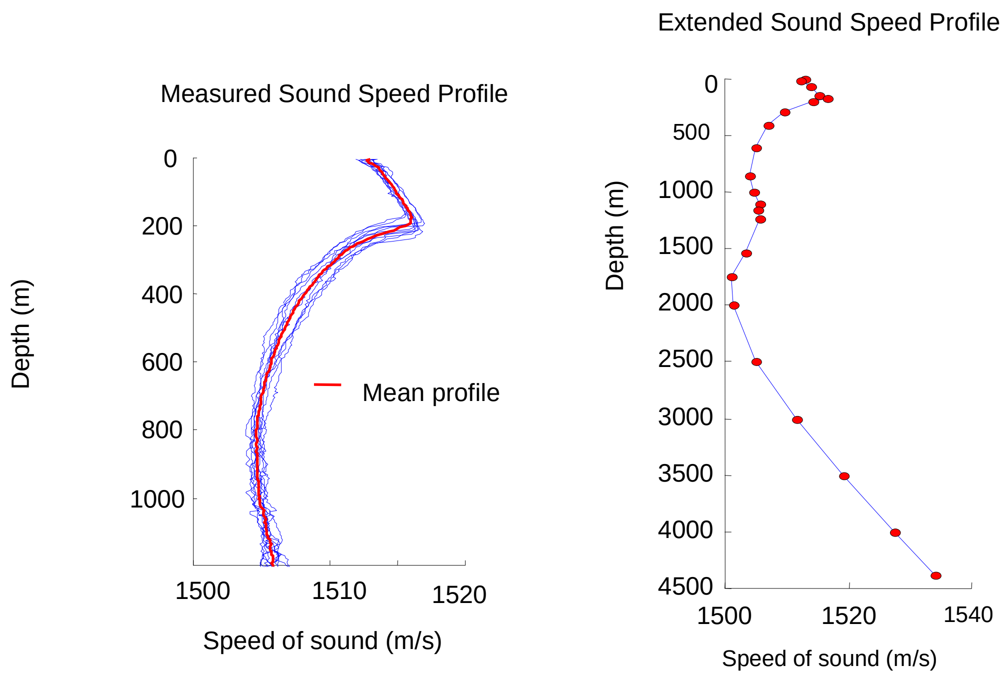



Figure 3  Sound speed profile

[*A number of sound speed profiles taken over a few days in the experimental region, together with the mean measured profile extended to 4400m using climatological data*]

Ray traces computed for the average profile are shown in Fig. 4 below.

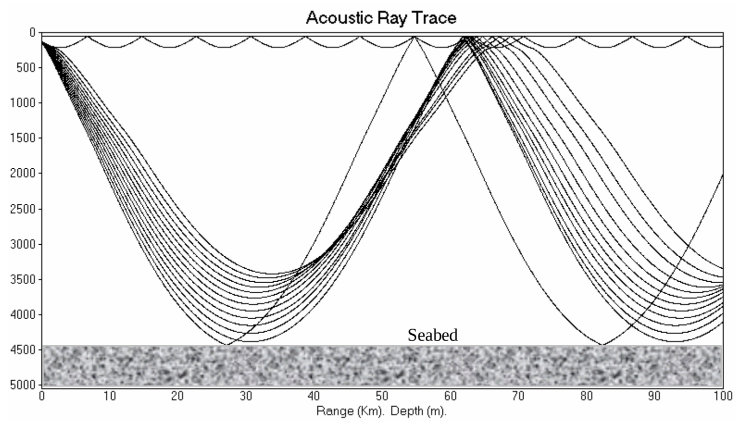



Figure 4  Ray traces

[*Ray traces calculated using the extended Sound Speed Profile show a deep path with a convergence zone at a range of about 65 km and a surface path confined to the upper duct of depth 200 m.*]

## RESULTS

The quantities investigated include the horizontal scale size of the acoustic intensity fluctuations transverse to the direction of propagation, the variance of the fluctuations, i.e. the "Scintillation Index" the correlation between intensity fluctuations at the different transmitted acoustic frequencies and finally the apparent velocity of the intensity pattern over the receiving array. Generally speaking the experimental results and the theoretical predictions agree quite well.

The Ribbon Width

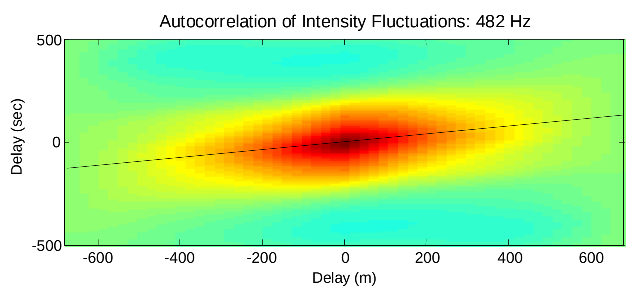
| $f$ | 482Hz | 680Hz | 740Hz |
|---|---|---|---|
| $\sqrt{\Gamma X / 3}$ | 4.2 | 6 | 6.5 |
| $L_I$ *(m)* | 507 | 355 | 328 |
| $T_I'$ *(sec)* | 90 | 75 | 80 |
| $L_I'$ *(m)* | 463 | 386 | 411 |

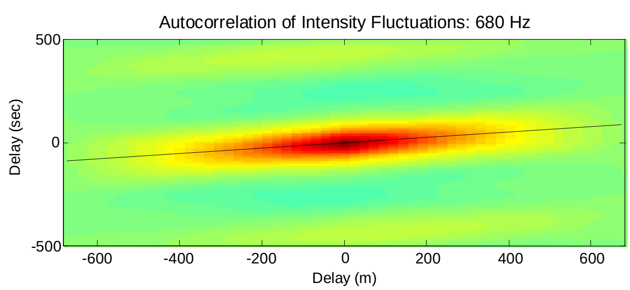
Table 1 The transverse width of the ribbons.

[*Shows the experimental L' and theoretical L values of the transverse horizontal widths of the high intensity features. Agreement is to about 10% on average*]

The Pattern Velocity

Theory predicts that for the case when both the source and receiver in an extended scattering medium move at the same speed parallel to each other with a velocity V then the observed speed of the intensity pattern at the receiver will be 2V. In the present case V is 5 kts, while the average value of the observed speed of the pattern at all three acoustic frequencies is 9.9kts. This can be seen from the intensity autocorrelation functions given below.



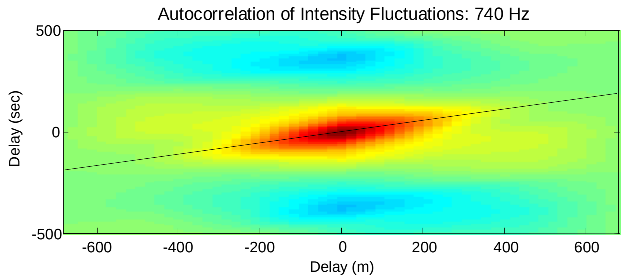



Figure 5 Space-time autocorrelation functions

[*Shows the autocorrelation functions of the intensity fluctuations in space and time axes. They have the general appearance of elongated ellipses, the slope of the major axis gives the apparent velocity of the intensity pattern*]

Cross-Frequency Correlation

The present experimental data provides us with evidence of how the high intensity ribbons at different acoustic frequencies are correlated with each other. Theory suggests that the large-scale features of the pattern will not change much, but that small scale features will decorrelate rapidly as the frequency varies. For active detection this might suggest that changing the frequency might not prove much help in producing a high intensity feature in a shadow zone where a target might be hiding. This theoretical conclusion is backed up to some extent by Figure 1 where we see that many of the high intensity features appear in the same place for the different acoustic frequencies. There are, however, examples of the opposite. If we compare the patterns in Fig. 1 we see that areas that are of very low intensity at 680 Hz contain high intensity features at 482 Hz.

## IMPACT/APPLICATIONS

An understanding of how the acoustic ribbon structure behaves as the acoustic frequency changes is essential in order to maximise the efficiency of operation of both passive and active sonars. It should allow us to calculate how much we can increase the chance of insonifying a submerged object by changing the sonar frequency. It can also tell us by how much we need to change that frequency. This knowledge can be very valuable when designing sonar equipment and also when deciding how best to deploy this equipment in practice. The present experiment backs up the theoretical framework of ocean acoustic scattering and the ribbon theory, giving us confidence that it can be used for the above purposes.

## TRANSITIONS

The results of this study have been applied to the study of acoustic propagation in the China Sea by Dr. Daniel Rouseff of APL Seattle (University of Washington). This has allowed us to make some preliminary estimates of how the ribbon structure and frequency diversity might be utilized when conducting operations in this region.

## RELATED PROJECTS

At present the Ocean Acoustic Group under Dr. B. J. Uscinski is engaged in developing a new form of active sonar. Some recent field trials have produced data that will be analyzed using the methods presented above. This will be a direct operational application and should provide us with valuable lessons of how to use our theoretical understanding in practical design and deployment.

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